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ANALYSES OF A COPRODUCTION ACQUISITION STRATEGY FOR THE LIGHT HELICOPTER PROGRAM (LH)

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April 1990

Prepared for
Office of the Deputy Director,
Tactical Warfare Programs

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The purpose of this study was to assess the potential cost savings of using a coproduction versus a competition acquisition strategy for the U.S. Army's Light Helicopter (LH) program (formerly LHX). The Army's Baseline Cost Estimate (BCE) is examined and reproduced before adjustments are made based on changes in the methodology used by the Army. The analysis of costs covers all production costs and considers the time value of money, the production schedule, and sustainment costs. Based on their analysis, the authors conclude that coproduction would be the least-cost acquisition strategy.

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PREFACE

This paper was prepared by the Institute for Defense Analyses (IDA) for the Office of the Deputy Director, Tactical Warfare Programs, under contract MDA 903 89 C 0003, Task Order T-F7-669, issued 13 December 1988.

The objective of the task was to assess the potential cost savings to the U.S. government that would result from coproduction of the Light Helicopter (LH) versus use of two full-facility production lines. The genesis of this assessment was the LH Milestone I Acquisition Decision Memorandum of 17 June 1988 from the Deputy Secretary of Defense to the Secretary of the Army, which conveyed the Defense Acquisition Board's decision to authorize the restructured LH program to proceed into the demonstration/validation phase. In that memorandum, the Army was directed to review the acquisition strategy to assess potential cost savings from coproduction versus two competing full-facility production lines.

The authors express their appreciation to Dr. Michael N. Beltramo, Mr. Arthur E. Strathman, and Dr. N. Keith Womer for their valuable insights and constructive criticism throughout the course of this study. Special thanks go to Dr. Karen Tyson, who conducted the research on prior acquisition programs and wrote Appendix A of this paper. The assistance of the IDA internal reviewers, Dr. L. Dean Simmons and Mr. Stanley A. Horowitz, is acknowledged, and the support and cooperation provided by Mr. Howard Gilby and his staff of the LH Program Manager's Office is greatly appreciated.

EXECUTIVE SUMMARY

The LH helicopter (formerly designated LHX) has been under development since the early 1980s as the planned replacement for the U.S. Army's light helicopter fleet. Presently in the demonstration/validation (DEM/VAL) phase of development, the program was originally intended to pursue a competitive acquisition strategy. In June 1988, when authorization to proceed into DEM/VAL was given, the Army was also required to review the LH acquisition strategy in order to assess the cost savings that might be gained from using a coproduction acquisition strategy rather than two competing full-facility production lines. Under the sponsorship of the Office of the Deputy Director, Tactical Warfare Programs, IDA was asked to conduct that assessment.

For the LH helicopter, IDA defines coproduction as the manufacture of a helicopter by two or more contractors, where each contractor provides some portion of the helicopter for final assembly, check out, and test at a single common facility. Using that definition of coproduction, the associated costs would be virtually the same as those of using a single contractor.

The Army's Baseline Cost Estimate (BCE) for the LH was predicated upon a competition acquisition strategy. IDA reviewed the Army BCE and supporting documentation to understand the methodology and cost factors used. IDA then used the same methodology and cost factors to model and reproduce the BCE. During this process, IDA identified areas where the BCE needed adjustment.

IDA removed all costs associated with the effects of competition to derive an estimate for a single producer. That adjustment resulted in an increase in the total procurement cost by $1.8 billion over the original BCE. Most of the cost difference was generated by removing the Army's 2-percent downward rotation of the production learning curve at lot 1. The Army had rotated the learning curve to account for the effects of competition; however, the program's system specification called for competition to start at lot 4. If the learning curve should be adjusted for competition, then the adjustment should be made at lot 4, not lot 1, as the Army had done. To see how the BCE would be affected, IDA rotated the cost-improvement curve 2 percent beginning at lot 4. That adjustment resulted in an almost identical increase of $1.8 billion over the original BCE. Table I

displays a summary of the costs for the Army BCE, IDA's reproduction of the BCE, the BCE adjusted to reflect a single producer, and the BCE adjusted for competition starting at lot 4.

Table I. Summary of Estimates

Cost Element	Army BCE	IDA BCE	Single Producer	Competition at Lot 4
Nonrecurring Production	721	720	637	720
Depot Equipment	170	170	150	170
Recurring Production	14,948	14,960	16,600	16,718
Engineering Change Proposals	759	635	699	711
Data	475	468	514	522
System Test and Evaluation	166	148	158	160
Training	1,318	1,312	1,312	1,312
Initial Spares	3,062	2,893	3,181	3,209
Project Management	1,758	1,786	1,988	2,009
Support Equipment	791	788	788	788
Other Production	2,391	2,380	2,380	2,380
Total	26,559	26,260	28,407	28,699

In Table I, the cost estimate for competition beginning at lot 4 is the most costly alternative; however, the cost estimates for a single producer and competition at lot 4 are essentially equivalent, given the level of accuracy of the estimates. Therefore, IDA looked for other data that might provide evidence as to which acquisition strategy would produce the least cost. IDA analyzed other aircraft programs to ascertain what learning or cost-improvement curve phenomena resulted.

Regression analysis by IDA of airframe production learning curves for three aircraft procurement programs (UH-60, F-15, and F/A-18) revealed that in each program the airframe learning curve was not a constant slope, but rather a two-part segmented slope. The slope of the improvement curve is rather steep early in production when production is building up to a peak production rate, then the slope flattens and remains fairly constant as long as there are no major changes in the production rate or in the aircraft itself. A typical segmented learning curve would be in the 80-85 percent range during production buildup and in the 90-95 percent range thereafter.

IDA evaluated three segmented learning curves and chose a 82/90-percent segmented curve for the LH program. This segmented learning curve was substituted for the Army's original 90-percent learning curve, which was rotated 2 percent. With this one exception, all other Army methodologies and cost factors were used. The segmented 82/90-percent slope was applied to both a competition and a coproduction acquisition strategy using the LH program procurement profile contained in the BCE. The results of using the 82/90-percent segmented learning curve for recurring production costs are presented in Table II. Both nonrecurring and recurring production costs are displayed because that is where cost differences will result.

Table II. Comparison of Nonrecurring and Recurring Production Costs (FY 1988 Dollars in Millions)

Cost Element	Competition (60/40 Split)	Coproduction	Cost Difference
Nonrecurring Production	$753	$582	29%
Recurring Production	16,873	15,356	10
Airframe[a]	5,273	3,974	33
Engine	1,167	1,167	0
Mission Equipment Package	7,971	7,894	1
Special Mission Equipment Package	1,005	1,099	-9
Armament	837	611	37
Aircraft Survivability Equipment	620	611	1

Note: Army costs used throughout.
[a] Slope for airframe was 82/90 percent.

The difference between coproduction and competition nonrecurring costs is about $170 million, or about 29 percent. This difference is due to the cost of tooling two production lines versus one. The other major differences are due to cost-improvement curve effects of recurring production. This comparison is between the competition 60/40 split estimate and the coproduction estimate for recurring production cost. In the 60/40 split, IDA assumed the contractor that won 60 percent of lot 4 had such an advantage over the losing contractor that the losing contractor never won 60 percent of any subsequent lots. In this scenario, the difference in airframe cost is about $1.3 billion in FY 1988 dollars, or about 33 percent less for coproduction.

IDA used the same engine costs for both competition and coproduction because the engine is to be government-furnished equipment (GFE). The Army has selected the T-800 engine to power the LH aircraft. In the engine full-scale development (FSD) contract there

is a guaranteed not-to-exceed unit production price per lot for the acquisition of 5,000 engines. Although this guarantee and a lot price adjustment formula are in the contract, competition between the two engine manufacturers may yield additional favorable pricing to the government.

Favorable price may come about because the tooling costs have been paid by the contractors; thus, there are no nonrecurring tooling costs to be offset. Also both contractors will be fully qualified to produce the entire engine; therefore, there are no costs to qualify a second source. Finally, this engine has the potential for a substantial commercial market, which may favor a lower price to the government.

Armament also displays a large percentage difference (37 percent) although the dollar amount is much smaller. This is due to the use of the same segmented learning curve as was used for the airframe. The Mission Equipment Package (MEP) is essentially the same under both acquisition strategies because most, if not all, of the MEP will be competed at the major subcontractor level. This is also true for the aircraft survivability equipment (ASE).

The task order also required that the time value of money be applied to the two acquisition strategy results. Both 5- and 10-percent discount rates were applied. The results did not change the relationship between the two acquisition strategies. This outcome was expected because the streams of money for the two acquisition strategies covered the same period of time and would expend at about the same rate.

The issue of coproduction versus competition principally involves the three cost elements of nonrecurring production (tooling), recurring airframe production, and recurring armament production. The average percentage difference of these three cost elements is 33 percent lower for coproduction. The cost of three other cost elements (Engineering Change Proposals, initial spares, and project management—discussed in the text of the paper) is derived as a factor of recurring production cost. The MEP, Special Mission Equipment Package (SMEP), and ASE are planned for competition procurement. The engine will be GFE and competed. Six other cost elements are unaffected by the acquisition strategy.

If coproduction is the acquisition strategy selected to procure the LH aircraft, IDA recommends that the FSD request for proposal (RFP) contain a definition of coproduction and require the contractor teams to submit a detailed plan for coproduction, including its management and organizational structure. Evaluation of the coproduction plan should be a criterion in the source-selection process.

Although IDA recommends coproduction as the LH airframe acquisition strategy, there are other factors to bear in mind. The data used as a basis to estimate costs of the LH aircraft were contractor price to the government data; however, the cost estimates made in comparing coproduction with competition does not attempt to reflect the price that a contractor may quote. The strategy that a contractor may adopt to set price is unpredictable, particularly in the short term. Costs do represent some constraint, because in the long term a contractor will not continue to price below cost.

A factor that could tend to serve as a protector to the government is not-to-exceed price by lot for a specified quantity of aircraft. In view of likely uncertain defense budgets in the future, a lot price adjustment formula similar in nature to the one negotiated with the T-800 engine producers should be negotiated for the LH aircraft. Once a not-to-exceed price has been established, it is unclear how a contractor may respond if the government also sought competition.

Based upon this analysis and the fact that the two prime contractor teams will be required to provide not-to-exceed production guarantees, IDA finds a coproduction acquisition strategy to be least cost for the government.

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I. INTRODUCTION

A. BACKGROUND

The Army has pursued the development and acquisition of a replacement helicopter for its light helicopter fleet since the early 1980s. Many of the aircraft in this fleet are about thirty years old and tactically obsolete. In December 1983, the Army started the advanced rotorcraft technology integration (ARTI) program as a precursor to full-scale development (FSD) of a new light helicopter, designated LHX.[1] That program involved the two airframe-contractor teams of (1) Boeing Helicopter and Sikorsky Aircraft and (2) Bell Helicopter Textron and Hughes Helicopters (since bought by McDonnell Douglas Aircraft and renamed McDonnell Douglas Helicopter Company).

The first phase of ARTI was to perform mission analysis, identify functional requirements for LHX systems, focus on pilot workload, and identify cockpit automation requirements. The second phase included assessment of cockpit technologies, definition of potential cockpit configurations, and preliminary design of candidate systems. The Army viewed ARTI as a means to reduce risks during FSD and as an aid to developing functional and performance specifications for writing requests for proposals (RFPs). The initial ARTI effort was completed and briefed to the government during May-July 1986.

In September 1986, the two prime contractor teams were awarded contracts to expand the ARTI effort to improve the quality of simulations of critical combat tasks. The Army proposed a demonstration/validation (DEM/VAL) strategy in April 1987. The thrust of that proposal was for development of a scout-attack/ armed reconnaissance helicopter and a utility helicopter that was to be about 70-percent common to the scout-attack variant. The utility helicopter would follow the scout-attack helicopter into production after about two years. Total production for these two helicopters was about 4,500 aircraft. The acquisition strategy was for competition during both FSD and production.

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[1] The LHX designation was recently changed to LH. The original documentation associated with the LHX designation retains that designation until superceded. In this paper the designation LHX and LH refer to the same helicopter.

A major issue that arose within the Office of the Secretary of Defense (OSD) was whether to proceed with a new development helicopter versus an advanced configuration. The Secretary of Defense signed a decision memorandum in May 1987, which authorized the Army to continue with the definition and design of the LHX Mission Equipment Package (MEP) but suspended additional airframe effort pending further study.

Two independent studies to evaluate competing airframe technologies were undertaken by IDA [1] and the RAND Corporation [2] at the direction of the OSD and the Army. The results of these assessments were presented to the Defense Acquisition Board (DAB) in November 1987. Following a review of the restructured LHX program in the context of the Army Aviation Modernization Plan, the Deputy Secretary of Defense signed a decision memorandum in January 1988, which authorized the Army to develop a lightweight, low-cost helicopter for light attack/armed reconnaissance missions. The initial efforts were to concentrate on the design of the avionics and MEP and on the integration of the Advanced Adverse Weather Weapon System, since named Longbow.

While the airframe and MEP efforts were getting underway, the Army was developing a new engine designated the T-800. Two teams were selected in July 1985 to compete during the initial development phase. These two teams were (1) Textron Lycoming and Pratt & Whitney Division of United Technologies Corporation and (2) Garrett Turbine Engine Company and Allison Gas Turbine Division of General Motors Corporation. The latter two companies formed a partnership and created a company called the Light Helicopter Turbine Engine Company (LHTEC). After a three-year engine development, the Army selected LHTEC to continue into FSD of its 1,200-SHP, turboshaft T-800 engine.

The firm-fixed price FSD contract between the Army and LHTEC has several unique features. It has guaranteed system specifications, not-to-exceed production prices for the average of the total buy and by program year lot, and ceiling costs for operation and support. Additionally, there is no government expense for tooling and facilities, and the contract contains a formula for price adjustment should the lot quantities change. The price-adjustment formula is structured such that the government receives the lowest price when the two engine manufacturers are each producing 50 percent of the annual buy quantity.

On 17 June 1988, the Deputy Secretary of Defense signed the LHX Milestone I Acquisition Decision Memorandum, which authorized the Army to proceed into the

DEM/VAL phase. That memorandum also required the Army to review the LHX acquisition strategy to assess potential cost savings from coproduction versus two competing full-facility production lines. Following this direction, the LHX Program Manager initiated action for a study by IDA under the sponsorship of OSD.

B. OBJECTIVE AND SCOPE

The objective of this study was for IDA to review the Army's proposed LHX acquisition strategy and to assess the potential cost savings from coproduction versus two competing full-facility production lines. IDA defines coproduction as the manufacture of an end item (e.g., the LH aircraft) by a partnership of two or more contractors in which each partner provides some portion of the end item for final assembly, check out, and test at a single common facility. Based on this definition, coproduction costs would be virtually the same as the costs of having a single producer.

The use of competition for acquiring the LHX is consistent with public law Title 10 USC 2438, which states that the Secretary of Defense may not begin full-scale development under a major program until an acquisition strategy is prepared and a report describing that strategy is submitted to the Armed Services Committees of both the House of Representatives and the Senate. This public law also stipulates that the acquisition strategy for a major program shall provide that competitive alternative sources be available throughout the program beginning with full-scale development and continuing through the end of production. This requirement for competitive alternative sources may be waived if complying with it during production would increase the total cost of the program. This study assessed which acquisition strategy would lead to least total cost of the LH program.

The scope of this study included all aspects of procurement and assesses the impact of the acquisition strategy on sustainment (operation and support) costs. The main emphasis was upon the prime contractors for the airframe; however, the major subcontractors for the MEP and T-800 engine were included in the analysis. The time value of money and the production schedule were also considered.

C. APPROACH AND METHODOLOGY

The initial approach was to collect historical data on each of the prime airframe contractors on each team. These data were business base information, book value of capital stock, net investment, and employment data. Projections of business and programs were also to be collected. From these data, IDA planned to calculate fixed and variable

overhead costs and estimate the impact on alternative aircraft procurements. Because the prime airframe contractors would not provide sufficient data due to its competition sensitivity, a generic approach to cost estimation was taken instead.

The first step was for IDA to review and understand the Army's Baseline Cost Estimate (BCE), including the assumptions and methodology used. Next, IDA applied the Army assumptions and methodology to reproduce the Army's BCE. IDA then proceeded to remove the costs that were identified as the effects of competition. This gave an estimated Army cost for a single airframe producer. This result was compared to the LHX BCE for competition.

During the process of reviewing and understanding the LHX BCE several factors were identified that required some adjustment. IDA estimated the production cost of the LH for both coproduction and competition using the Army methodology and cost factors except for the learning curve and the lot at which competition begins. These two estimates were compared with each other and with the Army's BCE.

Several ground rules were established for the study. The principal ground rules were:

- Costs will be presented in constant FY 1988 dollars.
- Deflation indices developed by the Naval Air Systems Command will be used to adjust then-year dollars to constant FY 1988 dollars.
- All elements of production as contained in the BCE will be considered in the assessment.
- Any potential impact of the acquisition strategy upon sustainment costs will be identified.
- Two discount rates, 5 and 10 percent, will be used to evaluate the time value of money.
- The total LH procurement program will be 2,096 aircraft.
- The maximum production rate will be 216 aircraft per year, which is 18 aircraft per month. This rate will be achieved at lot 6 in the BCE procurement profile.
- In a competition acquisition strategy, each prime airframe contractor will tool to 60 percent of maximum production rate, which is 11 aircraft per month.
- The T-800 engines will be government-furnished equipment (GFE).

Also, specific documentation was identified that contained information and data essential to the IDA assessment. Three documents basic to the analysis were the following:

- The Army's LHX BCE, dated 29 April 1988 [3]
- A listing of a 1,290-pound installed MEP, dated 13 February 1989 [4]
- An LHX group weight statement, dated 28 November 1988 [5].

D. OUTLINE OF THIS PAPER

The remainder of this paper is divided into three sections. Section II contains descriptions of the Army's methodology for deriving the Baseline Cost Estimate for the LH and of IDA's attempt to reproduce that estimate, including adjustments. In Section III, IDA's analysis of these results are described in terms of production cost, the time value of money, the production schedule, and sustainment costs. Finally, in Section IV, we present our conclusions and recommendations for the least-cost acquisition strategy for the LH.

II. DATA

IDA's approach was to understand first how the Army's BCE was derived and then to reproduce the Army estimate by using the BCE equations and cost factors. From this work, we were able to identify areas where IDA differed with the BCE methodology. These differences led to adjustments, which are discussed later in this section.

A. THE ARMY'S BASELINE COST ESTIMATE (BCE)

Many of the cost elements that comprise the Army's BCE were estimated as a factor of nonrecurring or recurring production cost. The cost elements were estimated as follows:

- Nonrecurring Production—parametric estimate, adjusted for UH-60 factor of nonrecurring production
- Recurring Production—parametric estimate, analogy to UH-60, AH-64, and OH-58D
- Engineering Change Proposals (ECPs)—factor of recurring production
- Data—factor of recurring production
- System Test and Evaluation (ST&E)—factor of recurring production
- Training—parametric estimate, U.S. Army Training Devices Program Manager
- Initial Spares—factor of recurring production
- Project Management—factor of recurring production
- Support Equipment—cost per site, analogy to UH-60 and AH-64
- Other Production
    - Software—parametric estimate, SECOMO Model
    - Army Program Manager—factor of Army in-house costs
    - Other—parametric estimate, analogy to UH-60 and AH-64.

The Army's methodology to estimate the cost of production was based primarily upon analogy to other aircraft. For example, analogy to the UH-60 was used for the airframe, and analogy to the AH-64 and OH-58D was used for the MEP. Airframe cost was derived from an airframe group weight statement extracted from MIL-STD-1374 Part

I, using cost per pound by major subsystem based on analogy to production lots 3, 4, and 5 of the UH-60. Factors were applied to the UH-60 data to account for differences due to LH technology and composite airframe structure, and size and complexity of the aircraft. To convert UH-60 costs to FY 1988 dollars, Army outlay rates and inflation indices were used. Table 1 shows the estimated costs that resulted from the Army methodology.

Table 1. The Army's Baseline Cost Estimate (FY 1988 Dollars in Millions)

Cost Element	Cost
Nonrecurring Production	721
Depot Equipment	170
Recurring Production	14,948
ECPs	759
Data	475
ST&E	166
Training	1,318
Initial Spares	3,062
Project Management	1,758
Support Equipment	791
Other Production	2,391
Total	26,559

Source: Reference [1].

From the UH-60 airframe production data a cost-improvement slope and a midpoint were determined. A theoretical first unit cost (T1) was derived by starting at the midpoint and backing up a 90-percent slope to the intersection of the ordinate on a log-log graph. From this theoretical first unit cost (T1) a 90-percent cost-improvement slope was assumed to represent a single production line. This 90-percent slope was rotated downward 2-percent to 88 percent beginning at lot 1 to reflect the effect of two competing production lines.

In the BCE, the low-bid winner was alternated between the two prime airframe contractors down a constant 88-percent learning curve; e.g., contractor "A" wins the odd-numbered lots and contractor "B" wins the even-numbered lots. This results in one contractor producing 1,056 aircraft and the other 1,040 aircraft.

The MEP costs were estimated by analogy, where applicable, by obtaining cost data on prior production of off-the-shelf items of avionics and by engineering judgment. Learning curves were varied from 90 to 95 percent by equipment item; e.g., steeper learning curves were used for new production items and flatter curves for in-production items. Learning curves also were rotated 2 percent to account for the effects of competition and the competition winner alternated down a constant learning curve, as described for the airframe.

B. REPRODUCTION OF THE BCE

IDA was able to reproduce the Army's methodology for estimating the BCE with the exceptions of the cost elements of Training, Support Equipment, and Other Production. The methodologies used by IDA for those elements are shown below:

- Training—cost per aircraft, analogy to UH-60
- Support Equipment—cost per aircraft, analogy to UH-60 and AH-64
- Other Production—cost per aircraft, analogy to UH-60 and AH-64.

The results are displayed in Table 2.

Table 2. IDA's Reproduction of the BCE (FY 1988 Dollars in Millions)

Cost Element	Cost
Nonrecurring Production	720
Depot Equipment	170
Recurring Production	14,960
ECPs	635
Data	468
ST&E	148
Training	1,312
Initial Spares	2,893
Project Management	1,786
Support Equipment	788
Other Production	2,380
Total	26,260

The IDA reproduction is about 1 percent under the Army's BCE. An exact dollar reproduction was not possible because IDA did not possess some of the detailed backup information and data used by the LH Program Manager's staff.

In the process of reproducing the BCE, we identified several areas in which we differed with the Army as to the methodology used. These areas and the resulting adjustments to the cost estimates are discussed in the following subsection.

C. ADJUSTMENTS

The Army's BCE was based on the assumption that competition would be used for the production of the LH. IDA removed all the credit taken in the BCE for the estimated effects of competition to derive an estimate for a single producer of the LH. This adjusted estimate is shown in Table 3. The cost for a single producer is about $1.8 billion greater than the original BCE.

Table 3. Adjusted Cost Estimates (FY 1988 Dollars in Millions)

Cost Element	Single Producer	Competition at Lot 4
Nonrecurring Production	637	720
Depot Equipment	150	170
Recurring Production	16,600	16,718
Engineering Change Proposals	699	711
Data	514	522
System Test and Evaluation	158	160
Training	1,312	1,312
Initial Spares	3,181	3,209
Project Management	1,988	2,009
Support Equipment	788	788
Other Production	2,380	2,380
Total	28,407	28,699

Also shown in Table 3 is an estimate adjusted for competition beginning at lot 4. In the Army BCE, the rotation of the cost-improvement curve from 90 percent to 88 percent was done at lot 1. The LHX system specification [6] clearly states that competition does not begin until after lot 3; thus, lot 4 is the earliest lot in the production schedule at which

competition could begin. IDA rotated the cost-improvement curve 2 percent beginning at lot 4 to determine the effect it would have on the cost of the LH program. As shown in the table, this adjustment increases recurring production cost from $14.9 billion to $16.7 billion, a difference of $1.8 billion. Based on these estimates, and given the current total quantity and lot size constraints, recurring production costs would be virtually the same whether competition or a single producer were used. For the purposes of our anlaysis, the costs associated with a single producer are the same as those associated with coproduction. Given these figures, competition seems to offer no advantage over coproduction.

Thus far, we have focused on understanding the LHX BCE, reproducing it, and adjusting rotation of the learning curve. Army cost data were used throughout; IDA did not introduce any new cost factors. The next section more clearly identifies the cost differences between coproduction and two competing production lines.

III. ANALYSIS

As part of our analyses, IDA reviewed evidence on competition from prior programs (see Appendix A). As a result of this review, our own analyses, and interviews with program office staff, we concluded that competition has not generally been proven to be a cost-effective acquisition strategy. Although competition has saved money in some cases, a universal application of competition has not been justified. It is important to be selective in deciding which programs to compete and when to compete.

Competition should be viewed as an investment, with fixed initial costs that need to be amortized over the course of the dual-source period. The larger and more customized the system, and the lower the quantity, the harder it is for competition to be viable because of the relatively larger investment.

That said, this section analyzes the effect on cost of competition versus coproduction in the case of the LH program. We first examine nonrecurring and recurring production, because that is where most of the cost difference will be seen. We also discuss the effect the acquisition strategy would have on the time value of money, the production schedule, and sustainment costs.

A. PRODUCTION COSTS

1. Nonrecurring Production

Nonrecurring production costs are the costs of tooling for the airframe, Mission Equipment Package (MEP), Special Mission Equipment Package (SMEP), Aircraft Survivability Equipment (ASE), and armament. Tooling for the engine is not an issue because the engine producers are paying for the total engine tooling. In the competitive strategy, each vendor must tool to produce 60 percent of the peak production rate. The combined tooling of two producers is therefore 120 percent. A single production line tools to 100 percent of peak production.

The cost differential between two producers each tooling to 60 percent and a single producer tooling to 100 percent is greater than the 20 percent excess tooling. In competition, each producer must provide initial or basic tooling plus rate tooling. A single

producer provides one set of initial or basic tooling plus a higher percentage of rate tooling because the production rate will be greater. Rate tooling is less expensive than initial tooling. For initial tooling, each contractor must design and fabricate tools, assemble jigs, fixtures, and master gauges. The cost of the design of tools and fabrication of master gauges is unaffected by the production rate.

2. Recurring Production

The answer to the question of whether coproduction is the least-cost acquisition strategy for the Army really lies at the level of the prime airframe contractor. The prime airframe contractors are primarily responsible for recurring production cost. These include fabrication and assembly of the airframe and the integration of the MEP, ASE, SMEP, and armament. The Army acquisition strategy is for competition of the major subcontractors, no matter which strategy is adopted for the prime airframe contractors. This portion of the analysis focuses on the prime airframe contractor's part in the total aircraft acquisition strategy, beginning with the airframe.

a. Airframe

We first looked at evidence from other aircraft programs to see how learning or cost-improvement curves were affected by the use of competition.[2] From that review, we concluded that the Army's rotation of the learning curve to produce a cost savings for competition cannot be supported with data from other aircraft programs. Although specific cases can be cited where competition apparently reduced the price paid by the government, these cases are for missile and aircraft engine programs. Generally, the data needed to positively identify the cause(s) of a reduced price are not available. Appendix A provides a discussion of the outcomes of past acquisition programs that were competed.

In the LHX BCE, the Army assumed a 90-percent slope learning curve that was rotated downward 2 percent to account for the effects of competition. UH-60 production lots 3-5 were regressed by the Army to determine an appropriate learning curve to apply to LH production. The 90-percent slope selected also was used to derive a theoretical first unit cost.

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2 The learning-curve theory was originally identified with production labor hours in the manufacture of aircraft. It has been subsequently applied to cost or price data; thus, the terminology of learning curve, cost-improvement curve, and price-improvement curve are often used interchangeably. The latter two terms differ in whether a curve is applied to cost data or price data.

IDA regressed the data for UH-60 lots 2-5 and derived a slope of 84 percent, which produces a higher theoretical first unit cost than does the 90-percent slope.

A second regression was performed by IDA on UH-60 production lots 5-9, for which a slope of 93 percent was obtained. These two regressions indicate that airframe production costs do not decrease at some constant rate over the total program. Rather, the curve is segmented. During the buildup to peak production, the production cost by lot proceeds down a rather steep cost-improvement curve. Once peak production is achieved, the cost-improvement curve tends to flatten.

There are several reasons for this phenomenon. As lot quantities increase, fixed costs are spread over a larger base; therefore, unit costs decrease. Also, as the production rate increases, the design matures, and engineering support can be reduced. Further, as the quantity produced increases, learning takes place in the form of both a more efficient work force and better manufacturing processes. The combination of these factors produces a steeper cost-improvement curve during the buildup to peak production. As the production rate stabilizes the effects of these factors contribute less to the unit cost, thus flattening the cost-improvement curve.

Two other aircraft programs, the F-15 and F/A-18, were analyzed and the airframe costs regressed. In each case a segmented curve was derived, which further supports the results of the UH-60 analysis.

IDA also differs with the Army's method of alternating the winner every other lot. In order for this concept to be viable, each prime airframe manufacturer would need other aircraft production work to absorb the constant increases and decreases in the work force. Experienced sources in the aircraft industry expressed serious doubt that such an acquisition strategy would work. Their belief is that the winner of the first year's competitive buy would have an advantage. That manufacturer would most likely continue to be the low bidder on all subsequent lots.

Cases have been documented where such aberrations occurred in the competitive manufacture of missiles. However, two points need to be made. First, these cases are the exception rather than the rule. Second, the manufacture of a missile, even the more sophisticated ones, is much less complex than the manufacture of an aircraft. The manpower requirements are drastically different.

As a result of this analysis, IDA chose to estimate the cost of LH production using two production lines on the basis that the low bidder for the first competitive lot continued

to be the low bidder on all subsequent lots. That manufacturer was therefore able to realize the effects of a learning curve over a larger quantity. Table 4 shows the production profile as presented in the Army BCE and the results of our 60/40 production lot split.

The last area in which IDA differed with the BCE method involved recurring cost elements whose costs were derived by applying cost factors to recurring production cost. IDA believes these six elements are essentially unaffected by the acquisition strategy selected, so their cost values were held constant under both competition and coproduction in the IDA estimates. The six cost elements are:

- Depot Maintenance Plant Equipment
- Data
- System Test and Evaluation
- Integrated Training System
- Support Equipment
- Other Procurement.

Together, they comprise about 20 percent of procurement cost.

To summarize, the IDA estimate of the recurring airframe production cost differed from the BCE as follows:

- IDA used a different cost-improvement curve to derive a theoretical first unit cost (IDA = 82%, BCE = 90%).
- IDA used a segmented cost-improvement curve for production of 82/90 percent rather than a constant 88-percent slope, as in the BCE.
- For the two-production-line acquisition strategy, IDA assumed that one contractor won 60 percent of all lots and the other contractor, 40 percent, whereas the Army BCE alternated the winner, which almost equates to a 50/50 split.
- IDA held six recurring cost elements constant rather than factoring off the recurring production cost, as in the BCE.

b. Engines

The current FSD contract for the T-800 engine with LHTEC contains guarantees for system specifications, not-to-exceed production prices for the average of the total buy and for each program year lot, and ceiling costs for the operation and support of the engine. The contract also contains a price-adjustment formula should the lot quantities change.

Table 4. Production Profiles

	Quantity by Fiscal Year												
	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Production Profile													
Quantity	24	48	96	144	180	216	216	216	216	216	216	216	92
Cumulative Quantity	24	72	168	312	492	708	924	1,140	1,356	1,572	1,788	2004	2,096
60/40% Competition													
60% Quantity	12	24	48	86	108	132	132	132	132	132	132	132	55
Cumulative Quantity	12	36	84	170	278	410	542	674	806	938	1,070	1,202	1,257
40% Quantity	12	24	48	58	72	84	84	84	84	84	84	84	37
Cumulative Quantity	12	36	84	142	214	298	382	466	550	634	718	802	839

Also, tooling and facilities will be provided at no expense to the government. The government intends to compete the procurement of the T-800 engine between Garrett and Allison beginning about lot 3.

Whether or not any price reductions will result depends upon the contractors' bids. It is not clear that dual sourcing in this case will cause the contractors to bid below their price guarantees. If the number of LH aircraft to be procured is reduced, the likelihood is that the lot sizes of the T-800 engine procurements will also be smaller. The government may ask for several bids under different conditions in order to gain the lowest price. The commercial market for the T-800 engine will also influence the price the government will be able to secure. Since the engine is GFE to the prime airframe contractors, IDA used the same engine costs for both the competition and coproduction estimates.

c. MEP, SMEP, and ASE

The avionics that make up these three categories are planned for dual sourcing. Many avionics items are being co-developed. Once production starts, the co-developers would split and bid against one another. This strategy should produce lower prices because avionics does not require the tooling investment of the prime airframe contractors, and automation of the manufacturing processes reduces the opportunity for learning-curve savings.

d. Armament

The decision of whether to compete the armament on the LH depends on the gun selected. Some of the alternatives have two potential producers, while others have one. The number of guns to be procured and at what production profile will influence the decision.

To estimate armament costs, IDA treated the armament the same as it did the airframe. Clearly, the integration of the gun and missile systems into the aircraft are part of the prime contractors' area of responsibility.

3. Results

The results of the production cost analysis are displayed in Table 5. This table includes both nonrecurring and recurring production costs, the six cost elements that are not sensitive to the acquisition strategy, and the other cost elements that factor off the recurring production cost. The nonrecurring cost (tooling) is 29 percent greater for

competition due to two contractors each tooling to produce 60 percent of peak production versus a single production line tooling to 100 percent of peak production.

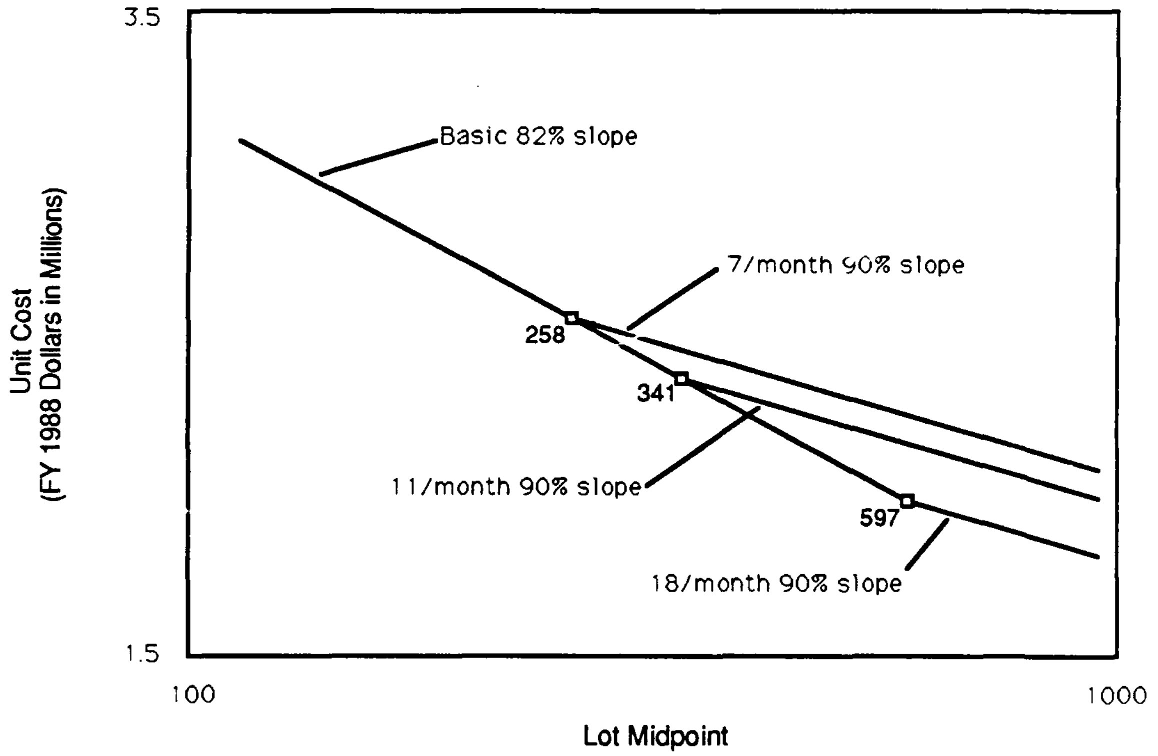
Table 5. Procurement Cost Comparison (FY 1988 Dollars in Millions)

Cost Element	BCE	Competition (60/40 Split)	Coproduction	Cost Difference
Nonrecurring Production	721	753	582	29%
Depot Equipment	170	150	150	0
Recurring Production	14,948	16,873	15,356	10
Airframe	4,254	5,273[a]	3,974[a]	33
Engine	1,152	1,167	1,167	0
MEP	7,047	7,971	7,894	1
SMEP	1,008	1,005	1,099	-9
Armament	948	837	611	37
ASE	539	620	611	1
Data	475	465	465	0
ST&E	166	147	147	0
Training	1,318	1,312	1,312	0
Initial Spares	3,062	3,172	2,966	7
Project Management	1,758	1,971	1,773	11
Support Equipment	791	788	788	0
Other Production	2,391	2,380	2,380	0
Total	26,559	28,716	26,550	8

Source: April 1988 BCE
Note: Army costs used throughout.
[a] A slope of 82/90 percent was used for airframe production.

For the airframe, two competing production lines are about 33 percent more costly than coproduction. The 33-percent difference in airframe cost is the result of the learning-curve effect. Figure 1 demonstrates this fact. When two airframe producers are competing on a 60/40 split, the low bidder receives 60 percent of the lot, which is 11 aircraft per month, assuming an annual peak production rate of 216 aircraft. The high bidder receives 40 percent of the lot or 7 aircraft per month at peak production rate. Since IDA believes the initial low bidder remains the low bidder throughout the production run, this producer goes

down the 82-percent learning curve until reaching a peak production rate of 11 aircraft per month at 341 aircraft and then flattens out on a 90-percent learning curve.



Note: Costs include airframe and auxiliary power unit.

Figure 1. Airframe Production Slopes

Conversely, the high bidder is producing at a lower rate and reaches the peak production rate of 7 aircraft per month at a lower quantity (258) on the learning curve where the curve flattens (to 90 percent). In our example, the number of aircraft produced annually by the single producer is the sum of the quantity produced by the two competing producers (18 aircraft per month), thus the single producer goes much further down the 82-percent learning curve before achieving peak production rate (597 aircraft), where the learning curve flattens to 90 percent. This same effect is realized for the armament cost.

Other cost elements that exhibit higher cost in competition are engineering change proposals, initial spares, and project management. All three cost elements are estimated as factors of recurring production cost; however, one would expect project management to increase in competition because the management of two contractors is involved.

From our analysis, coproduction by the prime airframe contractors appears to be the least-cost acquisition strategy. Coproduction has the potential to save the government about $2.1 billion.

B. TIME VALUE OF MONEY

The task order required the time value of money to be considered in the analysis. IDA selected two discount rates to evaluate the effect of the time value of money. A lower rate of 5 percent and a rate of 10 percent, as prescribed in OMB circular A-94 [7], were used. The results of the discounting are displayed in Table 6. The relationship of the costs did not change after applying the discount rates. This was an expected outcome because the streams of money in both the competition and coproduction acquisition strategies are expended over the same time period in approximately the same amounts.

Table 6. Time Value of Money

Procurement Cost	BCE	Competition (60/40 Split)	Coproduction
Constant FY 1988 $	26.6	28.7	26.6
Discounted 5%	18.6	20.5	18.9
Discounted 10%	13.8	15.2	13.9

C. PRODUCTION SCHEDULE

IDA examined the proposed LH FSD and production schedule for concurrency between these two acquisition phases. The concept of concurrency has both "good" and "bad" connotations. Both no concurrency and too much concurrency in an acquisition program are considered to be bad. The goal is to achieve a reasonable degree of concurrency that keeps the airframe contractor's team together so that little or no break occurs between the fabrication of FSD aircraft and Low-Rate Initial Production (LRIP) aircraft. This continuity also permits the contractor to demonstrate producibility of the aircraft so that when the full production decision is made at milestone III B, the contractor is ready to respond. A major disadvantage to concurrency is the risk that early LRIP aircraft may require retrofitting due to changes made as a result of testing; therefore, in order to obtain an acceptable degree of risk, a reasonable amount of concurrency is desirable.

In order to assess the reasonableness of the concurrency in the LH program, IDA compared the LH schedule to those of other, prior aircraft programs. LH FSD is scheduled to start with contract award in January 1991 and to continue for 69 months. LRIP is scheduled to commence with contract award in November 1994. This time is milestone III A of the acquisition process and coincides with early user test and evaluation (EUTE). Long-lead procurement funding precedes the LRIP contract award by about one year. On this schedule there is concurrency between FSD and LRIP of about 24 months. The LH program schedule for FSD and early production is displayed in Figure 2.

The LH procurement profile in Table 4 depicts a doubling of the procurement quantity of aircraft by lot for the first three lots, i.e., 24, 48, and 96 aircraft. This is a reasonable buildup of production rate from the aircraft manufacturer's viewpoint, but may seem high for LRIP. However, the comparison should be made on the basis of aircraft delivered. Given the current LH production schedule, it is estimated that about 16 aircraft would be delivered by milestone III B, full-rate production. We would have liked to compare this number against prior aircraft programs; however, these data were not available for most programs reviewed.

An IDA Paper entitled "Assessing Acquisition Schedules for Tactical Aircraft" [8] analyzed eight aircraft programs. A common datum was the time in months following the start of FSD that the 24th aircraft was delivered. This datum can be used as a measure of concurrency. The smaller the number of months, the greater the degree of concurrency and vice versa. For the eight aircraft programs that were analyzed, the 24th aircraft was delivered between 46 and 77 months (an average of 63 months). The 24th LH aircraft delivery is estimated to occur during the 75th month. From this perspective one can conclude that the LH program has reasonable concurrency.

Another measure of concurrency is a comparison of the time after start of FSD that the last FSD aircraft was delivered with the time after start of FSD that the first production aircraft was delivered. The closer these two times converge, the greater the concurrency. For seven of the eight aircraft in [8], these times varied between 0 and 4 years, the average being 1.7 years. The time for the eighth program, the AV-8B, was 17 years. The LH is scheduled to deliver the last FSD aircraft in January 1994 and the first production aircraft in March 1996, 2 years and 2 months later. Once again, this measure indicates the LH has reasonable concurrency.

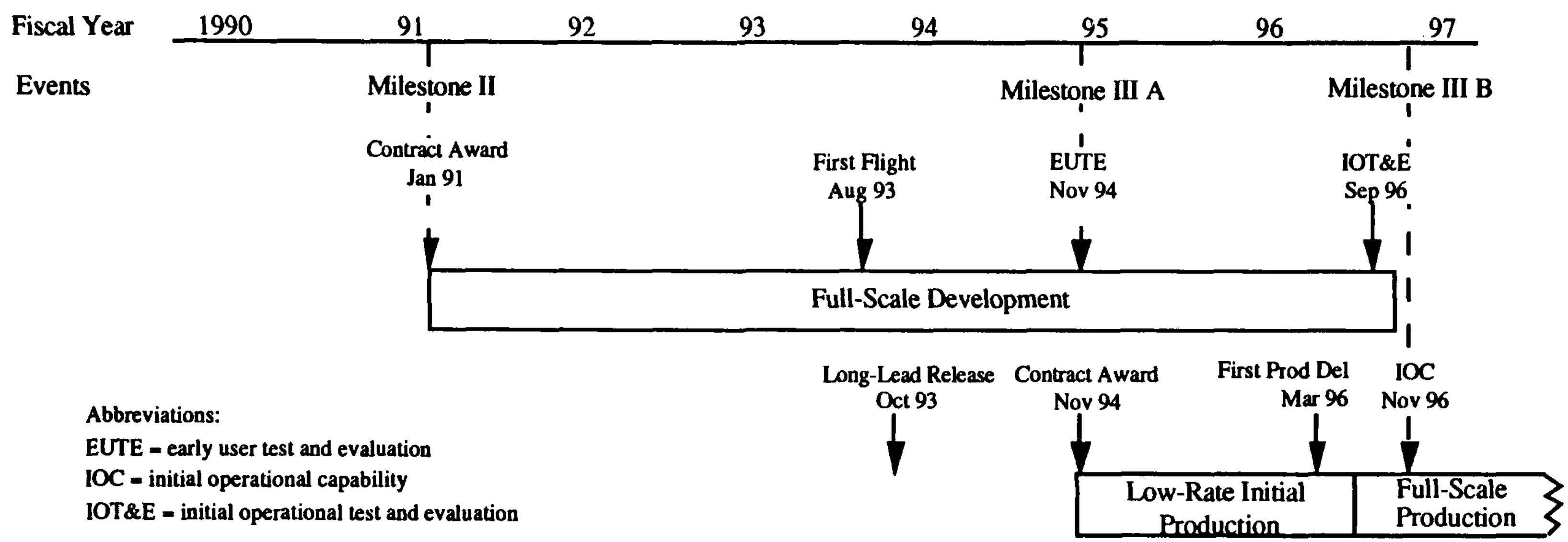


Figure 2. Program Schedule

A similar measure of concurrency is the time span between milestones III A and III B (i.e., the authorization to commence LRIP and the authorization to start full-rate production). These data were available for five of the eight programs in [8]. The time span between these two events ranged from 0 to 21 months and averaged just over 12 months. The LH program's time span is a conservative 24 months.

Based on this review, we conclude that the LH program has reasonable concurrency and only a moderate risk in the number of aircraft that may be subject to retrofit.

D. SUSTAINMENT COSTS

The task order required an examination of the potential cost impact of the acquisition strategy upon sustainment (operation and support) costs. IDA was unable to quantify the potential cost impact that either acquisition strategy may have upon sustainment costs; however, several qualitative comments can be made.

The acquisition strategy that has the greatest potential to increase sustainment costs is competition. Having two suppliers of an item poses the risk that the items produced will not be identical and therefore not totally interchangeable. This condition portends of stocking two sets of spares, not having the correct spare when needed, and of technicians installing the wrong look-alike component. Past experience has shown this condition to be more prevalent in the area of avionics. In the past, competitors have been permitted to build an item to have the same form, fit, and function; however, two electronic items with the same form and fit, may not function the same. Thus, interchangeability would be lost and two sets of parts required.

The way to eliminate this problem is to require each manufacturer to build to print. This ensures identical items and total interchangeablity. We believe this strategy is important to the LH program in that most of the electronic components of the aircraft rely heavily on modules. We do not believe the Army can afford, from either a cost or an operational viewpoint, to have aircraft components and parts that are not totally interchangeable.

We believe coproduction at the level of the airframe prime contractor reduces the risk of not having total interchangeability because the successful team would be responsible for maintaining configuration control. In addition, in the case of coproduction, the government would have one airframe contract to administer rather than two, as would be

the case with competition. This reduction in administration should both reduce cost and improve the efficiency of oversight.

IV. CONCLUSIONS AND RECOMMENDATIONS

IDA finds that coproduction of the LH helicopter at the level of the prime airframe contractor is the least-cost acquisition strategy. Three cost elements are the primary drivers of this finding: the nonrecurring production cost, recurring airframe production cost, and recurring armament production cost. These costs are 29, 33, and 37 percent, respectively, less than competition. Additional tooling and the learning curve provide the major portion of these cost differences. Of the other cost elements, the engine is GFE and planned for competition, the MEP, SMEP, and ASE are planned for competition, three cost elements (ECPs, initial spares, and project management) factor off recurring production cost, and six cost elements were unaffected by the acquisition strategy.

Coproduction may also provide the added benefit of reducing the risk of an adverse impact on sustainment costs. The team selected to proceed with FSD and production should provide overall configuration management and control over engineering change proposals, thus reducing the potential for components produced by two sources that are not completely interchangeable. Coproduction will permit the Army to do all the air vehicle contracting with one party, thus minimizing contract administration costs.

Coproduction is a relatively new method of procurement in the aircraft industry. The Navy has procured the F/A-18 as a joint development arrangement, and the Marine Corps has the V-22 aircraft in joint development. There is little or no precedent in the aircraft industry where there has been co-development of an aircraft followed by dual sourcing. It is not clear how applicable the theory and methods developed for leader-follower competition are to competition following joint development. The rationale for the transfer of competitive cost data from other systems procured in other environments to an aircraft program as a predictor of the outcome of competition is also unclear.

Unless there is an adequate production quantity to be procured, dual sourcing is not a viable option. In the near term, and with the likelihood of declining defense budgets, coproduction appears to be all the more sound.

Finally, if coproduction is the acquisition strategy selected to procure the LH aircraft, IDA recommends that the FSD RFP contain a definition of coproduction and

require the contractor teams to submit a detailed plan for coproduction, including its management and organizational structure. Evaluation of the coproduction plan should be a criterion in the source-selection process.

Section 2438 of title 10 United States Code (USC) entitled "Major programs: competitive alternative sources" addresses the requirement for the Secretary of Defense to prepare an acquisition strategy for a major program, and to submit a report describing that strategy to the Committees on Armed Services of the Senate and House of Representatives. This report is required prior to the beginning of full-scale development.

Subsection (b)(1) of section 2438 title 10 USC expands the requirements to include:

> The acquisition strategy prepared under subsection (a) for a major program shall provide that there will be competitive alternative sources available for the system (and each major subsystem) under the program throughout the period from the beginning of full-scale development through the end of production.

The law allows this requirement to be waived if it can be shown that competitive alternative sources would increase the total cost of the program. Specifically, subsection (c)(2) of section 2438 title 10 USC states:

> In preparing an acquisition strategy for a major program, the Secretary may waive the requirement of subsection (b) with respect to production under the program if the Secretary determines that the application of that subsection to production under the program would increase the total cost for the program.

The results of our analysis clearly demonstrates that two competing production lines would increase LH procurement cost by about $2 billion. The R&D and sustainment costs are unaffected by these results; therefore, the total program cost would be increased by about $2 billion. The IDA analysis forms a basis for the waiver provided for in subsection (c)(2) of section 2438 of 10 USC.

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APPENDIX A.

ISSUES IN PLANNING FOR COMPETITION: EVIDENCE FROM PRIOR ACQUISITION PROGRAMS

ISSUES IN PLANNING FOR COMPETITION: EVIDENCE FROM PRIOR ACQUISITION PROGRAMS

The LH program office will decide between competition and coproduction strategies within the next few months, before the full-scale development RFP is issued. IDA reviewed evidence on competition from prior programs. As a result of this review, our own analyses, and interviews with program office staff, we conclude that competition has not generally been proven to be a cost-effective acquisition strategy. While there have been cases in which competition has saved money, a universal application of competition has not been justified. It is important to be selective in deciding which programs to compete, when to compete, and how to compete.

Competition should be viewed as an investment, with fixed initial costs that need to be amortized over the course of the dual-source period. Past reports of savings in dual-sourced programs have had serious methodological difficulties.

There are potential non-monetary benefits to competition, including enhanced surge capability and greater contractor responsiveness to government needs. These may be considered by the government to be sufficiently important to override cost considerations.

A decision to undertake competition should be based on a detailed plan for its implemntation and should consider all potential costs and benefits.

GOALS AND HISTORY OF COMPETITION

Defense acquisition has a long history of competition. The Armed Services Procurement Act of 1947 required that contracts for property or services be formally advertised. OMB Circular A-109 directs that competition be used throughout a program, particularly during design and development. Competition at that point has the advantage of allowing the exploration of different alternatives. Competition often has been used in full-scale development. More recently, however, the government has emphasized competition in production, the explicit goal being lower prices and, possibly, better performance.

In the 1980s, Congress prescribed production competition. In the Defense Appropriations Act of 1984, Congress required that any major acquisition program have either a certification that the system would be procured in insufficient quantities to warrant

multiple sourcing or a plan for the development of two or more sources. The Competition in Contracting Act of 1984 (CICA) established requirements for maximizing competition. Competition was to be the norm; exceptions were to be justified. CICA required the appointment of competition advocates to review acquisition strategies. It both provided for specific procedures designed to guarantee that all vendors could bid for a proposed procurement and established protest procedures. Additional legislation—the Department of Defense Procurement Reform Act of 1984, the Small Business and Federal Procurement Competition Enhancement Act of 1984, and the Defense Procurement Improvement Act of 1985—also aimed to increase competition in defense contracting.

In addition, the Defense Department has encouraged competition. The Defense Acquisition Improvement Program (the Carlucci Initiatives), instituted in 1981, includes an initiative to increase competition in the acquisition process. The Packard Commission recommended the use of commercial-style competition. It recommended development of a waiver before hardware could be uniquely developed for the military.

Competition has a number of applications in defense procurement. The types of items that the government buys can be thought of as being along a continuum with respect to quantity and complexity. Small, uncomplicated items that the government buys in large quantity over the years are easy to compete. In many cases, these items are standardized, and multiple sources are relatively easy to obtain.

At the other end of the continuum, major weapons systems are developed on a customized basis and produced in relatively small numbers. It is not possible to simply decree "competition" in this environment and expect the same results as with standardized products.

Complete replication of commercial competition in major defense acquisition has not occurred and is not possible. For example, the Navy has only recently stopped requiring cost and pricing data in dual-sourced programs [A-1]. In a truly competitive environment, the government would not care what costs are, but only what prices are. However, the requirement of cost and pricing data made competition easier to evaluate. One might also argue that, in a situation in which the government pays start-up expenses, it is entitled to this information. In another example, in a truly competitive situation, contracts would be winner-take-all. However, in the typical dual-source procurement, the loser is guaranteed a share in order to maintain its production line. As is discussed later,

this guaranteed share is an important factor in evaluating potential costs and benefits of competition.

In the Army, competition has been used in the lower tiers in the past. In addition, major systems such as Shillelagh, Hellfire, Stinger, Dragon, and SINCGARS have been dual sourced. However, the LH program would be the first time that an Army helicopter was dual sourced. Helicopter makers have no experience at government dual sourcing at the prime level.

POTENTIAL BENEFITS OF DUAL-SOURCE COMPETITION

In the short term, the benefits of dual-source competition in major systems might be expected to include:

- Lower overall costs to the government
- Increased contractor responsiveness to government needs
- Enhanced system quality and reliability.

The rationale for the belief that dual-source competition lowers costs comes from the view that defense procurement should parallel the commercial world as closely as possible. In the commercial world, multiple firms compete for business, and this competition, in theory, holds prices down to the level of marginal cost plus a normal profit. In the traditional cost-plus contract, there is no particular incentive to hold down labor and materials costs, which can be passed directly on to the government. The government faced the possibility of contractors "buying in" by bidding low to win the development contract, and then raising prices in a cost-plus sole source environment. The government has used incentive fees or award fees to try to change the incentive structure.

However, competition can be regarded as a stronger way to increase the government's leverage throughout the production process. Because the government does not have a monopoly supplier, suppliers can be expected to be more responsive to the government's wishes throughout the program.

While contractor responsiveness benefit is difficult to quantify, program officials generally state that competition has made contractors more responsive. Particularly after a long period of sole sourcing, contractors may become complacent.

Enhanced quality and reliability is included by contractors as an attractive feature for government purchasers. A number of competitive programs we studied, including

Tomahawk and the alternative fighter engine, were motivated more by quality considerations than by cost.

Longer-term benefits could include:

- Enhanced industrial base for particular systems
- Increased capital investment by contractors.

The transfer of technologies and cross-fertilization of ideas in a dual-sourcing situation can be of benefit in broadening the base of suppliers for DoD. This is true of leader-follower systems, and particularly true of joint venture teaming. Dual sourcing also makes interdiction more difficult in wartime, since suppliers are geographically dispersed. In peacetime, strikes and other events are less likely to disrupt supply completely if there is more than one source.

An example of increased investment by contractors is the case of the Tomahawk missile. The contractor for the program built a plant especially for the missile's production. This allowed the contractor to optimize production specifically for Tomahawk, rather than having to adapt existing facilities.

There is, however, another school of thought that suggests that competition deters investment [A-2, A-3]. The reasons cited for this possibility include the additional uncertainty that competition imposes and the desire to avoid transferring technology to rival firms. Contractors may have to commit resources in advance of the contract award due to long-lead items. In the current uncertain budgetary climate, even if contractors commit resources, the planned quantity might not be acquired.

COSTS OF DUAL-SOURCE COMPETITION

In the short term, the weaknesses of competition include additional costs in areas not found in single-source production:

- Competition typically requires an up-front investment for tooling, equipment, qualification, and government administration to establish a second source. Management and administration at the contractor level are duplicated. If contractors tool to the highest level they can be expected to produce, there will be excess capacity. Maintaining those idle facilities costs money.
- By splitting a buy between two contractors, the government may give up some economies because the full benefits of learning and high-rate production are not realized. The learning curve relationship indicates that marginal costs decline relatively quickly with cumulative production. If a buy is split between two

sources, cost declines might not happen as quickly. In addition, the economies of scale from larger buys, could be diminished by having two sources.

- If multiple configurations are required, support costs may increase. For example, in the Air Force engine competition, two separate configurations and two repair networks have to be established to support the two variants, the F100 and the F110. We have no information on whether or not this has increased support costs.

Insufficient attention has been paid to the potential long-term weaknesses of competition. Are the benefits of competition a one-time effect, or can they be sustained over time? Production competition in major systems must be viewed as an investment decision. The potential reduction in procurement costs must be weighed against additional up-front costs and increased government administrative costs. This tradeoff is unique for each program.

METHODS FOR EVALUATING THE EFFECT OF COMPETITION

Learning-Curve-Based "Shift and Rotate" Methods

A standard method for evaluating the impact of production-level competition on program costs was developed in an IDA study of 20 competitive items [A-4]. This study greatly influenced subsequent evaluations. The approach involves comparing the observed competitive unit price with a predicted sole-source unit price.

The underlying assumption is that production costs are characterized by a learning curve. This curve is specified as:

$$Y = aX^b,$$

where

Y = cost of producing the Xth unit

a = first unit cost

X = unit number of lot midpoint

b = parameter used to calculate slope.

The unit learning curve formulation is regarded as preferable to the cumulative average formulation. This is because the unit curve reveals changing cost behavior more readily, while the cumulative average formulation changes only slowly.

More detail on the method is found in the Defense Systems Management College handbook on competition [A-5]. The method avoids the most obvious early pitfalls of the learning curve methods, such as lack of discounting. The steps in using this method are as follows:

(1) Estimate single-source recurring production costs by fiscal year in constant dollars based upon progress curves and expressed as contractor price.

(2) Estimate competitive recurring production costs by fiscal year in constant dollars based upon progress curves. Reasonable assumptions must be made concerning shift and rotation and the second source progress curve.

(3) Calculate potential savings by subtracting (2) from (1) by fiscal year.

(4) Calculate net potential savings by subtracting annual incremental government costs, stated in constant dollars, from (3).

(5) Estimate nonrecurring start-up costs, stated in constant dollars, by fiscal year.

(6) Estimate incremental logistic support costs, stated in constant dollars, by fiscal year.

(7) Calculate a net present value of competitive versus sole-source production costs by subtracting the discounted costs (5) and (6) from the discounted benefits (3).

(8) Compare discounted, constant, and then-year dollar estimates of single-source and competitive production.

(9) Conduct detailed sensitivity analyses to investigate the effect of changes in key assumptions on the estimate of savings, and to develop a range of likely estimates.

The strength of the "shift-and-rotate" method is its reliance on well-understood and recognized methods. Its weakness is its reliance on cost-based methods to evaluate prices, which may bear no predictable relationship to costs. The learning curve theory was designed for recurring labor costs. There is no a priori reason to expect that prices will follow similar patterns.

Early evaluations of competition had several major weaknesses. Sometimes, price-improvement curves were labeled as learning curves. In addition, some early studies failed to recognize the early fixed costs of competition, such as tooling, qualification, and administrative costs [A-4]. Finally, early studies failed to discount the stream of net benefits to get to the present value concept. Thus, future benefits were over-valued relative to present costs. [A-4, A-6, A-7].

The lack of data is also a major problem. To have confidence in the shape of a learning curve, eight data points are typically required. However, analyses often have been based on four or fewer points, as Pilling [A-8] notes.

Break Even Method

The break-even method, as developed by Margolis, Bonesteele, and Wilson [A-9], is a prospective method. The method is based on the price-improvement curve, but it includes adjustments for fixed overhead and the costs of a duplicate set of tooling. The method weighs the projected cost of continuing with a single source (based on experience with the price-improvement curve) against the projected cost of establishing a second source and the recurring costs of two sources.

The method has the advantage of avoiding direct estimation of the least-understood term, the recurring costs of the second source. It tells the analyst what value of second-source cost would be required for the government to be indifferent, or to break even, between the sole-source and dual-source acquisition strategies. This value can be calculated after there has been some sole source experience, using the relationship:

$$TC_{c2} = TC_{ss} + INVESTMENT_{ss} - TC_{c1} - INVESTMENT_{c} ,$$

where

TC_{c2} = Total recurring cost for Competitor 2

TC_{ss} = Total recurring cost of the sole-source supplier after competition begins

$INVESTMENT_{ss}$ = Remaining investment required to bring the sole source to full production capability

TC_{c1} = Total recurring cost for Competitor 1

$INVESTMENT_{c}$ = Investment required to establish the dual-source production capability.

The reasonableness of this "break-even" amount can then be assessed using the cost from the sole source over the same quantity interval. Experience has shown that, when the savings required from the dual source cost experience are 25 percent or less, competition is likely to produce enough savings to offset the investment costs. When the required savings are more than 25 percent, competition is unlikely to work.

While this method has considerable advantages, it also has some problems. Its value is limited, because at least some sole-source experience is necessary. It also assumes a prior strategy on the part of the government to produce sole source, while leaving open the possibility of dual sourcing. Often, the decision to go dual source has to be made

earlier. Nevertheless, within a relevant time frame, the method improves greatly on past approaches.

Behavioral Considerations

Advocates of behavioral methods for evaluation attack cost-based approaches. In a competitive environment, contractors charge prices, not costs. Therefore, behavioral factors need to be considered [A-10].

In a leader-follower situation, the first source may choose to raise prices immediately before competition starts, perhaps to take profits at that time. Beltramo [A-11] found this in 3 of 46 systems he examined. Conversely, in 6 of the systems, Beltramo found a substantial drop in prices immediately before competition, perhaps in an attempt to persuade program officials that a second source was unnecessary.

Therefore, it is important to consider contractor strategies when evaluating competition. In any given year, the contractor may choose to price based on factors other than costs. For example, a contractor might decide to try for increased market share at the expense of short-term profits. This allows them to retain labor that might otherwise have to be laid off. Alternatively, the contractor might decide to specialize in being a follower, as many have suggested that Raytheon has done.

Business Conditions Analysis

The price-improvement curve methods are based on technical production relationships. As a result, they ignore the potential impact of overall business conditions on the potential benefits of dual sourcing.

It makes sense to think that companies, in deciding how to bid in a dual-sourced program, consider their financial positions at the time. When there is a lot of production going on and industry is operating near capacity, companies are likely to be reluctant to take smaller profits in order to win business. In contrast, when industry is operating well below capacity, firms are hungry for business and will be more willing to reduce prices in order to win business.

Greer and Liao [A-12] recommend analysis of business conditions as a criterion for determining whether a given dual-sourced program is likely to cost less than a sole-source program. The basis for the method is empirical analysis of outcomes of past competitions. Using data on seven past competitions by Beltramo and Jordan [A-13], they estimated

price-improvement curves with a capacity utilization term. Capacity utilization was found to be statistically significant in determining whether or not competition brought savings. As a rule of thumb, they propose that competition be considered only when aerospace industry capacity utilization is less than 80 percent during the dual-source period. (They also found that sole-source program costs are influenced by capacity utilization, but in the opposite direction. When capacity utilization is high, costs are lower.)

This method has the appeal of being simple to implement using readily available data. It does, however, require a forecast of the capacity utilization index. Attempts have been made to make the capacity utilization index specific to the firm or the plant. Greer and Liao tested several alternative formulations, but none was consistently better than the industry-level indicator. They argue that this result is sensible. Even if one firm is operating well below capacity and is thus particularly "hungry," that firm would be unwilling to reduce price if the rest of the industry is doing well and bidding higher.

Winner-Take-All and Quantity Splits

Beltramo [A-14] concluded early on that winner-take-all competitions were far more effective than split buys. Greer and Liao [A-15] reinforce that conclusion.

In addition, the quantity split to the different sources is important. In choosing quantity splits, the desire to save money is in conflict with quality concerns and the desire to maintain two sources. In order to save money with dual sourcing, the closer to a winner-take-all situation in any given year, the better. That maximizes the incentive to the contractors to lower prices. However, a losing contractor might shut down production completely in a losing year. This would result in a loss of production capability and possibly a reduction in quality. Therefore, dual-source programs typically guarantee a percentage of production to the loser.

If this percentage guarantee is too low, the negative effects noted above can occur. On the other hand, if it is too high, a firm can game the system by bidding high enough to lose, then make profits on the high-priced guaranteed production. In theory, under this system, a loser who chooses a good strategy might receive higher percentage profits than a winner.

Empirically, Greer and Liao recommend a quantity split of 85 to 90 percent to the winner as optimal for saving money. However, recent competitions have had quantity splits as low as 60 percent to the winner, hardly sufficient incentive to win. According to

the Greer/Liao model, a winner's split of 60 percent is associated with savings only when capacity utilization is below 66 percent, a situation that has occurred only once in the last 30 years, in 1971. (Capacity utilization has been under 70 percent in only five of the last 30 years.)

EVALUATION OF PRIOR COMPETITIVE PROGRAMS

To examine the evidence on competition, we reviewed information on several programs from studies on competition by IDA, RAND, and the services (particularly the Navy) [A-4, A-6, A-7, A-8, A-16, A-17, A-18, A-19, A-20]. The types of programs include simple electronics programs, subsystems (aircraft engines), and such major acquisitions as tactical munitions (both air-launched and surface-launched) and a strategic missile. Among the many competitive programs included in the review are the F100/110 and the F404 alternative fighter engines and the following missiles: Imaging Infrared (IIR) Maverick AGM-65D/F/G, Tomahawk ground-launched cruise missile (GLCM), Sparrow AIM-7F and AIM-7M, HARM, Hellfire, TOW (tube-launched, optically tracked, wire-guided), Sidewinder AIM-9L and AIM-9M, Phoenix, basic Stinger, Shillelagh, and Dragon.

Of the above categories, the simple electronics are omitted, because they are less likely to be related to a major technological system like LH. However, the results of these studies indicate favorable potential for competition in this area. Some of the studies were previously discussed in the methods section.

In this section, we first discuss the engine subsystems, then move to a general discussion of the missiles. Next, the Army Hellfire program is highlighted, followed by a more detailed evaluation of the tactical munitions programs. Finally, a summary of the evaluations is given.

Aircraft Engines

The aircraft engine industry is an example of a situation in which competition appeared to have shock value. It was successfully applied twice in an industry in which it had not occurred before.

In the first case, the alternative fighter engine competition, Pratt & Whitney was the long-established leader in production of the F100 engine. The Air Force became dissatisfied with the reliability of the engine and decided to pay for further development of

the F110 engine by General Electric (GE) as an alternative. The subsequent competition did save money [A-21], and the Air Force also reports greater satisfaction with Pratt & Whitney's responsiveness to requests for spare parts.

In the F404 competition, GE was the leader and Pratt & Whitney, the follower. The competition resulted not from specific dissatisfaction but from general DoD and Navy policy. Again, the competition saved money. In addition, the government recently exploited an apparent cost advantage of the leader by doing a multi-year sole-source procurement.

It remains to be seen, however, whether this apparent advantage of competition will persist in the long term. Would a rational contractor be willing to make the investment in tooling if it suspects that its facilities will soon be idle? Might contractors engage in "competition learning" after a series of experiences with competition, thereby learning how to "game" the system?

Tactical and Strategic Missiles

The following results have been observed from evaluations of tactical and strategic missile competitions:

- In the IIR Maverick program, competition has so far resulted in increased costs. However, it is possible that the government will achieve savings if it continues to acquire these missiles through FY 1997 as planned. [A-22]
- In the Sparrow AIM-7F program, research [A-13, A-22, A-23] found no evidence of savings from dual sourcing.
- In the Tomahawk missile program, unpublished analyses by the program office and the Naval Center for Cost Analysis (NCA) show cost savings over sole source (also see [A-22]). There also appear to be methodological problems with the outyear savings estimates by the NCA. The dual-source learning curves were not statistically significant, so a 90-percent learning curve was assumed for the outyear dual-source estimates. In addition, the amount of savings and the extent to which savings are due to rate effects are disputed.
- In the HARM program, lower prices from the threat of competition resulted in a decision not to dual source. Incumbent Texas Instruments dropped its price by $209 million for the period FY 1983-85 and by $1.2 billion for the period FY 1983-89 in order to stay sole source [A-24].

- In the Hellfire program, there is no evidence of savings from competition. However, a second source was established at no apparent cost to the government [A-25].
- Berg, et al. [A-26] found no savings in the Sidewinder AIM-9L competition, but savings of about 11-12 percent were found in the AIM-9M competition.
- In 1987, the Naval Center for Cost Analysis examined eight cases of competition for cost savings [A-23]. Five of the eight programs (Sidewinder AIM-9L, armored box launcher, CG-47 cruiser, LSD-41 landing ship dock, and Mk 182-1 chaff cartridge) had associated net price savings, or at worst, an approximate breakeven. Estimates of net savings ranged from 4-24 percent of estimated total sole-source price. Two programs (Mk 46 Mod 1 and AIM-9M) had a net price loss. AIM-7F had savings if Lot 3 is the assumed start of competition, but a loss if Lot 5 is the assumed start.
- Berg, Jondrow, and Pisani [A-27] used a pooled sample of 18 missile programs over the period 1970-84. They found that competition had a negative effect on cost, but it was not generally statistically significant.

The Hellfire Missile

The Hellfire program is of particular interest to the Army because it is an Army program, and because the competition was fairly recent. Hellfire is an air-to-ground missile system that uses semiactive laser terminal homing guidance. Relative to other tactical munitions programs, Hellfire had a successful development, with low schedule growth and very low cost growth—only 1.09. The program had a stretch index of 1.2, which is very low even when compared with other competitive tactical munitions programs. The program ended up acquiring almost double the number of missiles planned. Production cost growth and total program cost growth were also low. Overall, by our measures of merit, the program looks successful.

The potential for competition occurred in 1977 when Martin Marietta submitted an unsolicited proposal for a privately developed alternative seeker. In December 1982, the government called for a dual-source competitive strategy. Each contractor would produce a small number of all-up rounds for certification in 1983, and head-to-head competition was to begin in 1984.

The contractors agreed to a technology transfer plan that established the data and knowledge that would be shared, and they established special accounts to document these costs. The contractors were allowed to recover up to $5,000,000 of these costs over the

first 6,000 missiles purchased from each contractor. If these costs were included in competitive proposals, they would obviously be included in the government's evaluation.

Bidding regulations required contractors to bid on a range of quantities from 1,125 through 4,500 missiles, and unit prices for any given quantity were required to fall on a single continuous logarithmic price line. Each of the two contractors was guaranteed a minimum of 40 percent in FY 1984 and 25 percent through the FY 1988 buy.

With respect to competition, the two contractors have alternated in winning the larger share of the buy in the four years for which data are available, 1984, 1985, 1986, and 1988. The 1987 buy was skipped, because both contractors were behind in deliveries.

Miller, Palmer, and Gogerty [A-25] found no evidence of a significant shift or rotation of the unit price improvement curve for recurring hardware costs. The slope of the unit recurring price curve, including both non-competition and competition years, is around 80 percent, neither unusually high nor unusually low. They concluded that the competition strategy was successful in the sense that there are now two prime contractors capable of providing fully assembled missiles, and that technology transfer and initial production facilitization costs appear to have been offset by the pressures of competition.

The alternating pattern of winning bids is interesting and is beginning to be seen in other programs. It appears that management strategy and not just cost plays an important role in determining contractor bids. In some sense, this alternating pattern may allow contractors to better plan for production. However, it does not necessarily lead to dramatic cost savings for the government.

Tactical Munitions

The analyses discussed above generally examine only competitive programs in isolation, with no use of non-competitive programs as a contrast. Evaluations typically consider whether competition saved money relative to what the program would have cost under a sole-source strategy. In order to make this evaluation, the analyst is required to assume the costs if the whole program were sole source, usually by extrapolating the sole-source phase experience. This approach may have serious problems. While it has the appeal of being the same program and the same technology, the sole-source phase of a competitive program may not be typical—Beltramo [A-11] has observed anomalies in the sole-source phases, particularly in the last sole-source year of a competitive program.

Therefore, an alternative approach to evaluating the impact of competition is to compare the outcomes of competitive programs with the outcomes of similar non-competitive programs. In order to do this, an outcome measure is required. Production cost growth—defined as the ratio between actual cost of the program and the cost estimate at Milestone II, adjusted for quantity and inflation—is one measure that can be used to evaluate both types of programs [A-22].

In this section, we evaluate competitive and non-competitive missile programs. Tactical missile programs were chosen, because the bulk of the competition in major systems has occurred there, and there is also a large population of non-competitive programs. We would expect, other things being equal, that competitive programs would have lower cost growth in production than non-competitive programs would have.

The sample consists of 16 tactical munition programs, nine competitive and seven non-competitive. All programs have at least three years of production data, and all produced at least 75 percent of their planned quantity. (The ten tactical munition programs that produced less than 75 percent of their planned quantity have atypical cost growth patterns, because their cost experience is weighted toward early production.) The non-competitive programs include Lance, Tow II, MLRS, Phoenix A, HARM, Improved Hawk, and Harpoon. The competitive programs include Phoenix C, basic Stinger, Sidewinder AIM-9L and AIM-9M, the Sparrow AIM-7F and AIM-7M, Hellfire, IIR Maverick, and Shillelagh.

Figure A-1 shows the production cost growth of competitive and non-competitive programs relative to program stretch. By observation, there is no obvious relationship between competition and lower cost growth. If there is any relationship at all, it appears that, controlling for stretch, production cost growth is *higher* for competitive programs.

Using statistical analysis, we tested whether competition was associated with a significant difference in cost growth. We found no statistically significant relationship between competition and cost growth.

Discussion of Evaluations

The evidence fails to demonstrate statistically that dual-source competition always reduces program cost. There have been a variety of evaluations of past competitive programs. Virtually all of the recent competitions discussed here are of the leader-follower

variety. Results of these evaluations of competition indicate a mixture of cost savings and added costs.

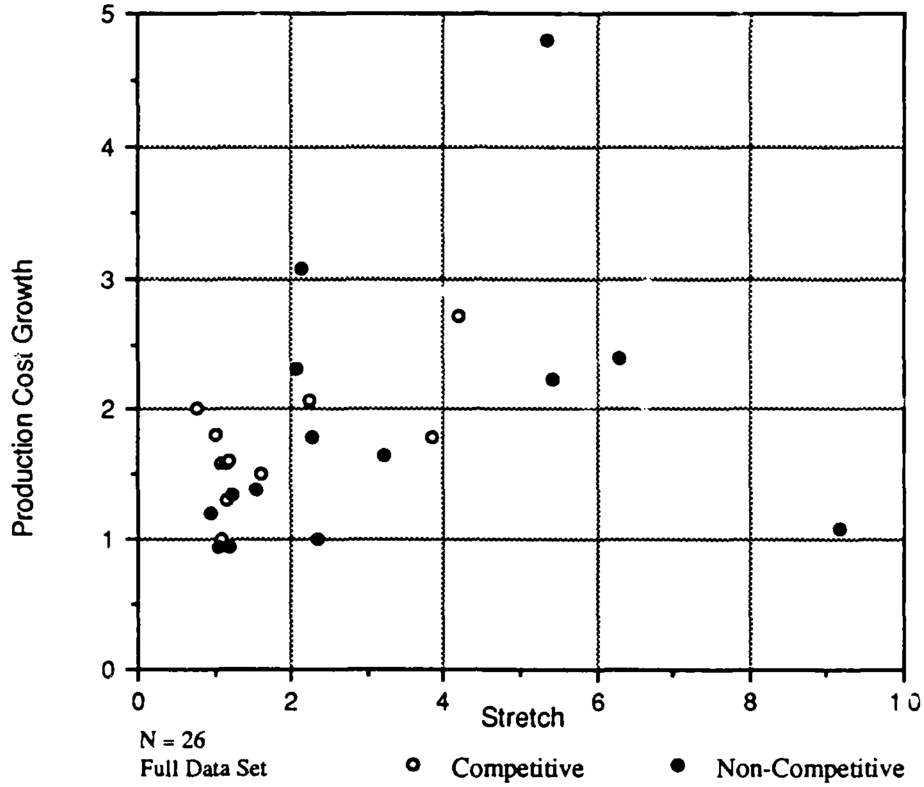

Figure A-1. Production Cost Growth and Stretch in Competitive and Non-Competitive Tactical Munitions Programs

CHARACTERISTICS OF SUCCESSFUL COMPETITION

If any threads of success can be drawn out of this review, some factors that may be related to successful competitions include:

- Relatively low-technology hardware (This would make it possible to transfer technology easily.)
- Large production quantities (These are necessary for reasonable competition to occur.)
- Proven designs
- At-rate production (This goes hand-in-hand with large production quantities.)
- Underutilized production capacity (Greer and Liao [A-14] noted that successful competitions occurred when capacity utilization was below 80 percent.

Also, when competition is done for the first time in an industry, competition may have shock value.

See, for example, the results of the aircraft engine competitions. Another possible mechanism, noted by Beltramo [A-28], is that the second source might bid naively low, because of lack of understanding of the difficulties associated with production.

CONCLUSIONS

Based on findings from a review of dual-source experience, we can make the following general conclusions and recommendations regarding competition issues:

1. Dual-source production should not be prescribed across the board for major systems. Competition can be of value in particular individual cases; however, it is very difficult to predict what those cases are.

Additional work needs to be done on criteria for competition. It should not be universally applied. The larger and more customized the system, and the lower the quantity, the harder it is for competition to be viable because of the larger investment.

2. In evaluating the possibility of cost savings from competition, it is recommended that more than one method be used. No single piece of evidence should be regarded as conclusive.

From our review, we have concluded that the results of retrospective evaluations of competition have contradictions. For example, in the case of the Sparrow AIM-7F, different conclusions occur depending on when competition was assumed to begin.

In addition, the methods used to evaluate competition so far have been defective. The learning curve shift-and-rotate method, which has been the most prevalent, has serious defects.

3. That cost savings from competition are uncertain should be recognized. It does not make sense to plan on large, immediate cost savings. Competition requires some up-front investment, and payback is over a number of years.
4. Specific guidelines should be established for competition, similar to those for multi-year procurement. Competition is best applied under the following conditions:
   - A large number of systems are required
   - A firm plan and stable funding are available
   - Break-even analysis suggests that costs can be recovered over a reasonable period.

- Technology transfer involved is relatively straightforward
- Adverse effects on other programs are negligible.

5. Benefits other than reduced prices may exist and need to be considered. Among these are increased contractor responsiveness, increased system reliability, and preservation of the industrial base.

6. Additional research should be done into the long-term effects of competition. Such research should go beyond the individual program to consider overall contractor strategies.

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ABBREVIATIONS

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ARTI	advanced rotorcraft technology integration
ASE	Aircraft Survivability Equipment
BCE	Baseline Cost Estimate
DAB	Defense Acquisition Board
DEM/VAL	demonstration/validation
ECP	Engineering Change Proposal
EUTE	early user test and evaluation
FSD	full-scale development
GFE	government-furnished equipment
LHTEC	Light Helicopter Turbine Engine Company
LRIP	Low-Rate Initial Production
MEP	Mission Equipment Package
NCA	Naval Center for Cost Analysis
O&S	operation and support
OSD	Office of the Secretary of Defense
R&D	research and development
RFP	request for proposals
SHP	shaft horsepower
SMEP	Special Mission Equipment Package
ST&E	System Test and Evaluation